Dental Emergence Among Urban Zambian School Children: An Assessment of the Accuracy of Three Methods in Assigning Ages

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ABSTRACT In situations where birth records are unavailable and stated ages are unreliable, the emergence of the permanent dentition can serve as an indicator of age. Due to substantial variation in the timing of tooth emergence, a sample (n = 721) of Zambian school children, with known ages, was examined to provide a tooth emergence reference standard for the area. Three methods for assigning ages were utilized and their accuracy assessed. A random test sample was withheld from the original study in order to further evaluate the methods' accuracy. The three methods—1) number of teeth, 2) regression and 3) probit analysis—were applied to Zambian children, and estimates of age were made. Predicted ages were compared to actual ages to determine the percentage of accuracy in three categories—±.5, ±1.0 and ±2.0 years—and paired *t*-tests were conducted. Each of the three methods was then applied to the test sample, and their accuracy was evaluated in the same manner.

Methods 1 and 2 were found to provide the higher percentage of correct ages within ±.5 years, assigning roughly 39% of both male and female children within this increment. This was also the case at the next increment, with methods 1 and 2 assigning a higher percentage (66–76%) of children to the ±1.0 year category, while the accuracy of method 3 was quite a bit lower. The results for the test sample were very similar to those of the main sample. The overall accuracy of methods 1 and 2 was very similar in both the main and test samples, while method 3 had lower accuracy and *t*-tests indicated significant differences. Therefore, due to ease of application in the field setting, method 1, mean age per number of teeth emerged, is the method of choice. Am J Phys Anthropol 102:447–454, 1997. © 1997 Wiley-Liss, Inc.

In much of the developing world, accurate recall of age is difficult to obtain, and birth records are often unavailable. When the growth and development of a child are assessed, accuracy of age is highly desirable since indicators of growth and physical development are age-specific. Tooth emergence, the emergence of a tooth through the gums, is commonly accepted as a means of estimating age (Steggerda and Hill, 1942; Voors and Metselaar, 1958; Bailey and Garn, 1986). There are several advantages to using the permanent dentition as an indicator of age in situations where records of age are not kept. Most notably, it is a quick and fairly noninvasive procedure requiring only sufficient lighting and a dental mirror, and it is objective since the teeth are either there or they are not.

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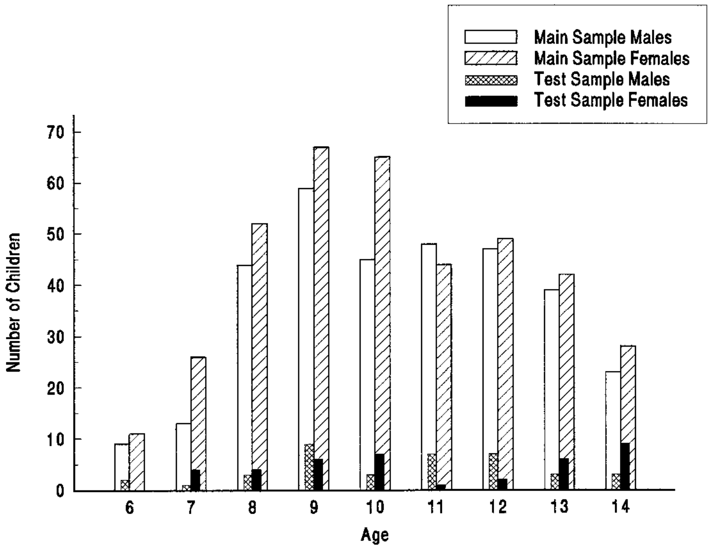

Fig. 1. Sample distribution, frequencies by age for both the main and test samples. Age groupings represent the center of the age distribution for the year indicated.

Construction of a population specific tooth emergence standard is necessary because there is substantial variation in timing of tooth emergence among populations with differing geographic origins (Garn et al., 1973; Bailey and Garn, 1986); therefore, a local population with known ages is used to provide the relationship between tooth emergence and chronological age. In the present study an urban sample of Zambian children, whose documented ages could be obtained, was examined in order to develop a tooth emergence reference for application to rural Zambian children of questionable or unknown age. Three methods for estimating age, based on the emergence of the permanent dentition were applied to this sample: 1) number of permanent teeth, 2) linear regression analysis, and 3) probit analysis. The results were then compared to one another and assessed for accuracy in assigning correct ages. The methods were also evaluated by comparing the accuracy of a subsample (or test sample) which was not a part of the original assessment.

SAMPLE AND METHODS

The sample in this study consists of school children from Choma, Southern Province, Zambia. Choma is a middle-sized urban center in which the population is predominantly Tonga (44% within the sample). The urban setting of Choma was chosen because it is on the line of rail and the major Lusaka-Livingstone road and provides a higher socioeconomic level in most cases than the rural areas of the province. Most importantly, by conducting this research in an urban school of higher relative socioeconomic level, I was able to obtain documented ages for the children (Gillett, 1995).

Each child underwent a visual inspection for the presence of the permanent dentition using natural light and on occasion a dental mirror. The status of each tooth was recorded on a diagram of the permanent dentition using a scale of 0–4 (Weiner and Lourie, 1969): 0, no tooth present; 1, crown of the tooth peeping or emerging through the gum; 2, crown of the emerging tooth less than halfway; 3, crown of the tooth more than halfway but not in occlusion; and 4, tooth fully emerged and in occlusion. For development of this tooth emergence standard, the sample was reduced from n = 721 to only those children with active tooth emergence. Therefore, a child was included if any one of the permanent teeth, I1 to M2, was still in stages 0–3 above. The age range became 5.5–14 years old, and the sample was reduced to 287 females and 256 males, the age distribution of which can be seen in Figure 1. The five point scoring system was not used to further refine the analysis for two

reasons. First, the assignment of a particular tooth to stage 2 or 3 was found to have low reliability (Gillett, 1995). Second, breaking the sample down into smaller units led to insufficient sample sizes in several age and emergence categories.

Prior to the reduction of the sample, 10% of the individuals were randomly chosen and withheld to be used as a test sample; their age distribution can also be seen in Figure 1. This group was withheld in order to test how well each method predicted age on a sample other than the one from which it was derived. The following three methods were then applied to the remaining 90% or main sample in order to develop the age estimation standard.

Method 1 was a determination of age based on the number of emerged permanent teeth. The numbers of emerged teeth were combined to form even numbered increments. (i.e., 1–2, 3–4, etc.) (Billewicz and McGregor, 1975; Brown, 1978; Hassanali and Odhiambo, 1981; Cashion, 1988). The average age of children with a given number of permanent teeth in occlusion (stage 4) or emerging (stages 1–3) was calculated, and a sex-specific chart was produced. This method is used with a child of unknown age by counting the number of permanent teeth present and assigning the mean age for that number of teeth from the chart.

Method 2 was regression analysis. The number of permanent teeth emerged (stages 1–4) was regressed against known age (Cashion, 1988), and sex-specific equations were derived. Since tooth emergence often has a curvilinear distribution, it is also useful to include the number of teeth as a squared variable. Both the number of permanent teeth (T) and the number of permanent teeth squared (T^2) were utilized to derive regression formulas. This method is applied to children of unknown age by entering the number of permanent teeth that are present (T) into the regression equation.

Method 3, probit analysis, is the method of choice in many studies (Cornfield and Mantel, 1950; Voors, 1957; Hayes and Mantel, 1958; Lee et al., 1965; Gates, 1966; Eveleth and Freitas, 1969; Friedlaender and Bailit, 1969; Richardson et al., 1975; Lavelle, 1976; Mayhall et al., 1978; Manji and Mwaniki, 1985; Blankenstein et al., 1990; Kumar and Sridhar, 1990). Probit analysis is also referred to as a dose/response study and is based on the presence/absence of a response. For tooth emergence, *dose* is synonymous with age and *response* with emergence. The probits, the result of a log normal transformation of the means, allow the dose/response relationship to be fairly linear and standard deviations to be derived for any point. The median age at which each particular tooth emerged (stages 1–4) was derived and a probit transformation applied (Finney, 1971). A sex-specific table of probits for each mandibular and maxillary tooth type was then compiled. For application to a child of unknown age, the particular teeth emerged are recorded, and the probit age for the tooth of latest emergence is assigned.

Estimates of age were then made for all children in the main sample using the three methods. For each method, the percentage of children accurately assigned a correct age was compared and the results analyzed in categories of $\pm.5$, ±1.0, and ±2.0 years from the correct age. The accuracy of the three methods was further assessed using paired *t*-tests between actual and assigned ages.

The ability of each of the three methods to assign ages to children other than those from whom the standard was derived was then evaluated using the test sample. Each of the three methods was applied to the test sample, and accuracy was evaluated in the same manner as with the main sample in categories of $\pm.5$, ±1.0, and ±2.0 years from the documented age.

RESULTS

The results of method 1, for the main sample, can be seen in Table 1. The mean age at which a given number of teeth is present is listed, and the table is divided by sex. It should be noted that there are no males with one to two teeth in the sample. Note as well that although the trend is for age to increase with increasing number of teeth, there are a few places where this does not hold true (e.g., 13–14 teeth in the males). This fluctuation suggests that this table would require smoothing for use in determining unknown ages.

TABLE 1. Mean age for a given number of permanent teeth present for children in Choma, Zambia[1]

Number of permanent teeth	Male			Female		
	n	Mean age in years	S.D.	n	Mean age in years	S.D.
1–2	—	—	—	3	6.07	0.25
3–4	2	7.15	1.20	3	6.73	1.17
5–6	8	6.66	0.71	12	6.83	0.84
7–8	12	7.69	0.81	7	7.54	0.97
9–10	25	8.25	0.87	22	7.84	0.76
11–12	58	9.39	1.17	55	8.53	0.97
13–14	26	9.32	1.11	38	9.34	1.09
15–16	19	9.58	1.23	18	9.65	1.38
17–18	12	9.97	0.90	17	9.64	0.90
19–20	15	10.96	1.29	19	10.06	1.15
21–22	9	11.52	1.00	12	10.33	1.05
23–24	21	12.03	1.07	17	10.94	1.52
25–26	12	11.28	1.01	26	11.00	1.10
27	8	11.66	1.28	9	11.59	1.16

[1] This table originally appeared in Gillett (1995).

TABLE 2. Probits with 95% confidence limits for children from Choma, Zambia

	Maxilla		Mandible	
	Probit[1]	95% confidence limits	Probit	95% confidence limits
Males				
M1	5.77	5.30–6.11	5.19	4.67–6.34
I1	6.63	4.78–7.41	5.79	5.44–6.06
I2	7.89	7.42–8.25	6.62	6.08–7.00
P1	10.06	9.88–10.23	9.95	9.17–10.71
C	10.42	10.23–10.61	9.90	9.73–10.07
P2	10.94	10.76–11.13	11.23	11.06–11.41
M2	11.46	11.29–11.65	11.30	11.19–11.49
Females				
M1	5.06	4.24–5.58	5.35	4.82–5.71
I1	6.47	6.19–6.68	5.31	4.77–5.67
I2	7.32	7.11–7.49	6.55	6.28–6.78
P1	9.30	9.13–9.46	9.51	9.35–9.67
C	9.81	9.64–9.98	8.87	8.71–9.03
P2	10.45	10.28–10.62	10.59	10.37–10.82
M2	11.18	11.01–11.35	10.74	10.58–10.90

[1] For explanation see the Sample and Methods.

Method 2, regression analysis, was performed on the main sample in two ways. The first equation type was the number of permanent teeth present (T) against age. In the second instance, the variables T and T^2 (the number of permanent teeth present squared), were regressed against age since dental emergence is not linear. It was found that although the multiple r and standard error of estimate (SEE) were very similar for both sets of equations, about 1 year, the second equation, because of its curvilinear nature, had a little better fit at both ends. The following regression equations were produced:

$$\text{Male: age} = 5.601887 + .311456T - .002168T^2$$

SEE: 1.07738

Multiple r: .85716.

$$\text{Female: age} = 5.898608 + .213325T + .000481556T^2$$

SEE: 1.07820

Multiple r: .85222.

Method 3, probit analysis, was performed on the main sample. Table 2, divided between mandibular and maxillary teeth, contains the sex-specific probits for tooth type with the 95% confidence limits. From this table one can see the following tooth emergence sequences for Zambian males and females.

Male:

$$M_1\ M^1\ I_1\ I_2\ I^1\ I^2\ C_.\ P_1\ P^1\ C^.\ P^2\ P_2\ M_2\ M^2.$$

Female:

$$M^1\ I_1\ M_1\ I^1\ I_2\ I^2\ C_.\ P^1\ P_1\ C^.\ P^2\ P_2\ M_2\ M^2.$$

Although differences in tooth order occur in the molar and incisor emergence patterns, after the emergence of I^2 tooth order is consistent between males and females with only slight mandibular and maxillary variation, and that is seen in P_1. Table 2 also demonstrates systematic advanced dental emergence in females, as would be expected.

The top half of Figure 2 contains the results of the accuracy of the three methods for the main sample. Methods 1 and 2 provide the greatest accuracy, with method 1 assigning 42% of male children and 37% of female children an age within a half year of their actual ages. Likewise, method 2 assigns 38% of the males and 39% of the females to this increment. Method 3 has less than a 30% accuracy rate for both sexes. At ±1.0 year, method 1 and method 2 were very similar, with, respectively, 67 and 68% accuracy for males and 71 and 67% accuracy for females. The accuracy of method 3 is quite a bit lower for both sexes. Methods 1 and 2, for both sexes, have more than 91% of

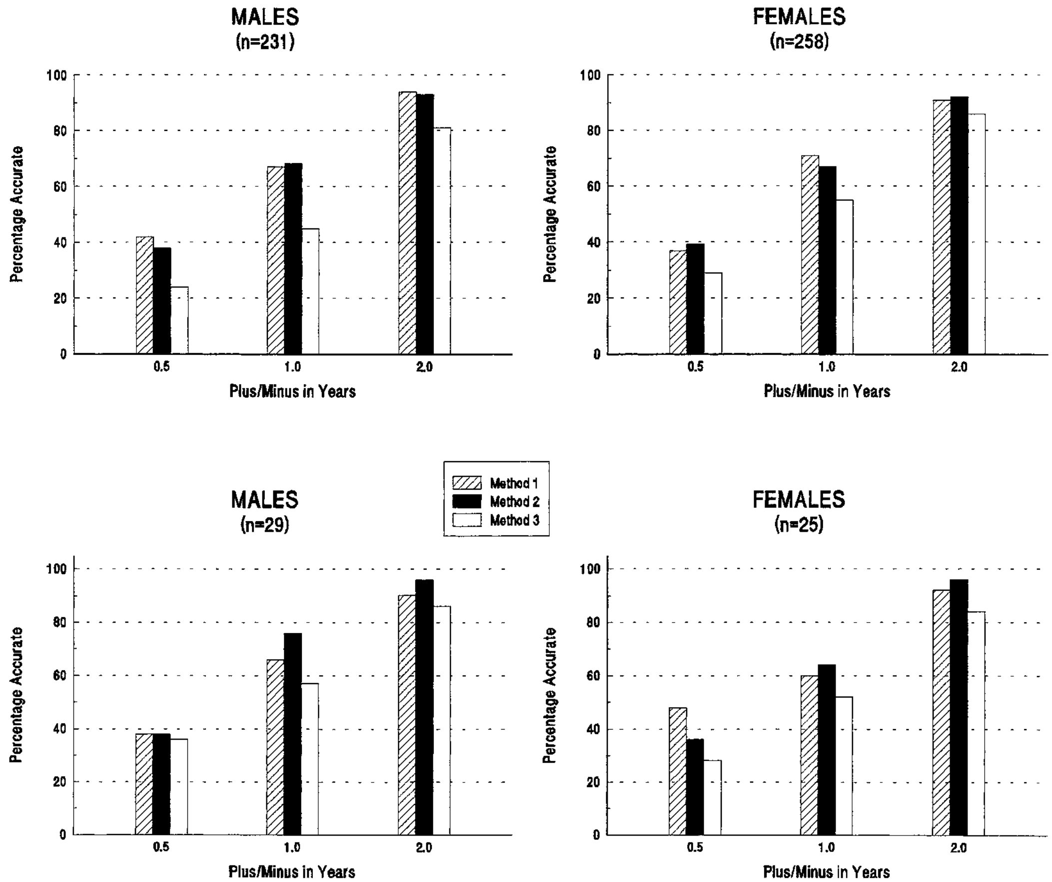

Fig. 2. The percentage of accurately assigned ages for each of the three methods by sex. **Top:** Main sample. **Bottom:** Test sample.

children being assigned an age within ±2.0 years of their actual age.

The results for the test sample can be seen in the bottom half of Figure 2. Once again the categories of ±.5, ±1.0, and ±2.0 years were used. These results are very similar to those for the main sample. The only notable exception is with method 3, in which the ±.5 year category the accuracy for females was only 28%. This is 20 percentage points lower than method 1. Method 3 falls below both methods 1 and 2 beginning at the ±1.0 year category for both males (57% accuracy) and females (52% accuracy). The results in the ±2.0 year category are almost indistinguishable from the main sample results, with only method 3 falling below 90% accuracy.

The ability of each of the three methods to assign a correct age was further analyzed using paired *t*-tests (Table 3). Cases were paired by sex and actual age. The mean difference at the sample level and two-tail probabilities indicate varying degrees of accuracy that are dependent on age. At the sample level, the only significant differences between actual age and predicted age were found in method 3.

DISCUSSION

Both the number of permanent teeth emerged (method 1) and probit analysis (method 3) are used regularly to examine population-specific dental emergence for descriptive purposes; however, a comparison of

TABLE 3. Comparison of t*-tests between actual ages and predicted ages by method for children from Choma*

	Main sample[1]		Test sample[2]	
	Mean difference	Two-tail probability	Mean difference	Two-tail probability
Male				
Method 1	−.02	.743	.03	.883
Method 2	.05	.514	.12	.542
Method 3	−.25	.013[3]	−.07	.803
Female				
Method 1	.09	.192	−.13	.582
Method 2	.08	.231	−.10	.661
Method 3	−.27	.001[3]	−.67	.009[3]

[1] This consists of 90% of the subjects and was used to derive the aging standards.
[2] This consists of a randomly selected 10% of the cases who were withheld for validation.
[3] Statistically significant.

the accuracy of these methods has previously not been performed. In comparing the three methods for application to a sample of children of unknown age, accuracy within ±.5 years is highly desirable, but ±1.0 year is usable. The standard deviations for age estimates made using method 1 (number of permanent teeth) are often a year or more, while the standard error in method 2 (regression) is 1 year. Method 3 (probits), however, provides 95% confidence limits often under 1 year. The tendency would be to expect method 3 to provide more accurate age estimates than the other two. This is not the case, with fewer than 30% of the children in the main sample being assigned an age within ±.5 years of their correct age as opposed to around 40% accuracy in methods 1 and 2. In the ±1.0 year category, method 3 is once again 10–20 percentage points lower.

When we consider the test sample, which was withheld before the three methods were applied to the main sample in order to derive ages from the number of emerged permanent teeth, we see similar levels of accuracy in method 3. Methods 1 and 2, however, allow us to assign accurate ages in the ±1.0 year category for close to 70% of the children in the main sample and the males in the test sample, while providing 60–65% accuracy for the females in the test sample. Based on this, and the fact that when paired *t*-tests were applied at the sample level method 3 had significant differences between actual age and predicted ages in both the main and test samples, method 3 (probits) is the least accurate application for assigning ages to children of unknown age.

The accuracy of methods 1 and 2, both of which are based on the total number of teeth present, in assigning correct ages is very similar overall. There does not seem to be a tendency for increased accuracy in either method 1 or 2 in comparison to the other. This finding is consistent with that of Cashion's (1988) study of Malian children. Additionally, in the current study this holds true for both the main and test samples. Of the two, method 1 (number of permanent teeth) is the method of choice. This decision is based on the ease of application in the field situation. It is by far easier to count the number of emerged permanent teeth, refer to a chart, and assign an age immediately than it is to have to plug the number of teeth into a regression equation and calculate the age.

The results presented here, therefore, lead us to question why probit analysis (method 3) worked relatively poorly in comparison to methods 1 and 2. This is especially relevant since probit analysis is used commonly throughout the literature to determine the median age of emergence of dentition. The appropriateness of this method has not been questioned when it has been applied to the determination of age for children of unknown age, even though such an evaluation would be critical to judge its accuracy.

One issue to be considered is whether or not the sample composition has affected the efficacy of the methods. I would argue that this is unlikely. It is necessary for the observations to cover the full range of 0–100% emergence in order to calculate probits. This sample is lacking male individuals in the category of one or two teeth emerged. The tooth this would most likely affect is M_1, since they are normally the first permanent teeth to emerge in this population. Individuals with no permanent teeth emerged were available to complete the frequency table. The tendency would be for the standard deviation for male M_1 to be smaller than it would otherwise be, because of the missing data.

Another possible factor that could have affected the efficacy of the methods is the

shape of the distribution of the data. If the distribution of observations is not level or rectangular, then a lack of data at either end could affect the mean emergence age. For example, a lack of data at the upper end would result in the underestimation of the mean, while at the lower end it would result in an overestimation. This effect was considered in the analysis of this data set, and differences between actual ages and predicted ages were examined both graphically and with paired *t*-tests for all three methods. No trends were observed. I would also argue that, through the use of a test sample to evaluate the accuracy of the three methods, distribution problems would be more likely to be apparent. The fact that the methods yielded much the same outcomes on the test sample as they did for the main sample would seem to minimize the chance that there was a distribution effect.

The difference between probit analysis and the other two methods is that ages predicted by probits are based on the median age of a single tooth, the latest tooth to erupt based on the population, while number of permanent teeth is based on all teeth present. For example, a child with 24 teeth present will not necessarily have the same 24 teeth present as another child of the same age. Accordingly, there is a higher variance around the mean age for a given number of teeth, in contrast to the precision implied by the individual tooth in probit analysis.

CONCLUSIONS

Until this study, there has been no direct comparison of the accuracy of the methods used here to determine chronological age. Probit analysis has been used commonly by researchers as a descriptive tool for the population they are examining. In studies where the assignment of an age to individuals of unknown age is the stated priority, the mean age for a given number of permanent teeth is the method of choice for its ease in application rather than its methodological accuracy. I would caution those interested in assigning ages to evaluate the accuracy of their method of choice. The findings presented in this paper suggest the use of the total number of teeth emerged is preferable when assigning ages. However, researchers who have tooth emergence data should evaluate the accuracy of age estimates made from their probits in comparison to those made by using the mean age for a given number of permanent teeth.

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